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EUXENITE AND ORTHITE ORE BEDS IN LIAONING PROVINCE

Liu Nai-hsin

/Figures referred to herein are appended./

Euxenite, although produced in small quantities, has become one of the most important uranium ores. In East Asia, the first euxenite was mined in July 1938 in Hai-ch'eng Hsien. (See "Euxenite and Orthite in Hai-ch'eng Hsien, Feng-t'ien Province," by Sakamoto Takao, Ikeda Sanse, Matsuda Kamezo, and Liu Nai-hsin, Japan Geological Magazine, Vol XLVI, May 1939, pp 250-251.)

The ore beds are located in Hai-ch'eng Hsien; the most important are those at San-t'ai-kou and Ta-fang-shen, northeast and east, respectively, of Hai-ch'eng-hsien, both at a distance of about 15 kilometers. This distance can be conveniently covered over a public highway in 2 hours by motorcar or in 4 hours by horse cart (Figure 1).

The San-t'ai-kou deposits are situated in Yu-chuang-t'un of Pai-shih-chai-ts'un, 15 kilometers directly northeast of Hai-ch'eng-hsien. The ore deposits lie within an area of mound-like hills about 1.5 kilometers south of San-t'ai-kou.

The Ta-fang-shen deposits are situated in the area under the jurisdiction of Wang-shih-pao-ts'un, 12 kilometers directly east of Hai-ch'eng-hsien. The ore deposits are some 600 meters north of Ta-feng-shen, and about 12 kilometers south-southwest of the San-t'ai-kou ore beds.

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A. Developments

The locale between San-t'ai-kou and Ta-fang-shen has long been known as a gold-producing area. Mining for gold dust by native methods has centered particularly in the vicinity of Yang-chia-nan-kou, Nan-kou, and T'u-niu-kou. During the period of Japanese occupation, this area produced feldspar and various forms of silica. The former was principally used as raw material for ceramic products and as a source of insoluble silicates; the latter for the manufacture of steel by the basic process for which purpose it was transported to the steelworks at An-shan.

Euxenite was discovered in the vicinity of the high-level silica quarries near San-t'ai-kou in April 1939 by two Japanese, Sakamoto Takao and Ikeda Sanae. From September to December of that year a prospecting party which included the author, Liu Nai-hsin, and a Japanese, Matsuda Kamezo, a member of the staff of the Geological Research Office, SMR (South Manchuria Railway), made a thorough and careful survey of the pegmatite rock veins in the San-t'ai-kou and Ta-fang-shen areas. Deposits of euxenite were found in Nan-kou and Ta-fang-shen as well as in San-t'ai-kou. In November 1940 and June 1943, Liu, equipped with an Empire Drill, prospected. In the riverbeds of the San-t'ai-kou area at a depth of about 25 feet, and at the bottom of a ravine at Nan-kou under some 10 feet of gravel, the presence of radioactive minerals was definitely established by tests made of the samples of the ore. Of the approximately 200 veins of pegmatite investigated, only six veins were found to contain euxenite and orthite, three in San-t'ai-kou, one in Nan-kou, and two in Ta-fang-shen. At the time of this prospecting, there was no opportunity to exploit the rare elements beyond taking steps to protect the natural mineral values of the area by the staking out, by the SMR, of some 30 mining claims in the San-t'ai-kou and Ta-fang-shen area. It was not until mid-1943 that the rapidly increasing importance of the rare-element-bearing minerals again brought these ore deposits to the attention of the world.

In 1944, when the world was entering the era of atomic energy, Japan's need for the rare-element minerals, especially uranium ores, became acute and this bed of mineral deposits became the only important source of uranium ores within the sphere of Japanese power.

In April 1944, the Manchukuo Mining Company began preparation for mechanized mining of these ores on a large scale. In December 1944, they started surface mining at the rate of 10,000-15,000 tons per month, which yielded about one ton of concentrate per month. During 1945, there was a decline in the quality of the ore and in the quantity of concentrate realized, as shown below (in tons, approximate figures):

Period	Amount Produced
1944 Dec	1.00
1945 Jan	1.00
Feb	0.75
Mar	0.80
Apr	1.00
May	0.50

The aggregate production of concentrate was thus less than 10 tons.

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B. Terrain

Within the area under discussion, the highest parts of the land are 100-200 meters above sea level, and 20-100 meters higher than the surrounding mound-shaped hills. The terrain has the appearance of the late Mesozoic era. This area is part of the watershed of the Sha River. The streams are all shallow with gravel beds. There are many small tributaries in the ravines. Accumulations of detritus blanket the lower half of the slopes of the mound-shaped hills.

C. Geology of the Area

The distribution within the area of the various kinds of rock is as follows:

Primary period layers of greenish schistose rocks and gneissose granite; and pervading these, countless veins of pegmatite, lamprophyre and quartz (Figure 2).

1. Granitic Rocks

These large masses of granite are found widely distributed in South Manchuria, and consist mainly of medium- and coarse-grained crystalline-porphyritic granite and black-mica granite, permeated by layers of schistose rocks and gneissose granite. Although it is not known in what period the intrusions occurred, the mass in general may be said to belong to the new granite system with the formation of aplitic granite and coarse- or medium-grained mica granite. The rock has a fine or medium-grained structure, is a dull brownish color, and consists chiefly of quartz, microclinic feldspar, plagioclase (albite, oligoclase) and orthoclase, and in lesser amounts, of black mica, phosphoric limestone, and zircon. This type of rock does not have veins of quartz and pegmatite.

2. Gneissose Granite

It is ash-white or dull reddish-brown coarse- or medium-grained material with a distinctly streaky structure. Principal contents are quartz, orthoclase, plagioclase, black mica, a small amount of hornblende, and occasionally some dull reddish phenocrysts of orthoclase. Less important contents are sphene and phosphoric limestone. The rocks permeate and break through the greenish schists and are penetrated by the new system rocks; besides this, lamprophyre, porphyrites, pegmatite, and veins of quartz are embedded in it. The period of intrusion was not the same as that of the new granite system, and is not definitely known, but it may have been in the Pre-Cambrian period.

3. Pegmatite

The pegmatite is chiefly imbedded in the layers or veins of gneissose granite of which there are upward of 200 layers, large and small. The veins or dikes are jumbled, irregular, and usually lens-shaped. The larger bodies are 10-20 meters wide and 50-100 meters long. Major contents are orthoclase, microclinic feldspar, perthite, plagioclase, and quartz. Minor contents are black and white mica, black tourmaline, and very little mafic mineral. The rare-element-bearing euxenite and orthite are found in only six veins of this rock of varied composition, coarse-grained and easily disintegrated feldspars and quartz.

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Tabulated Summary

Locality of Ore Beds	Ore	No of Beds	Mafic Minerals	Mother Rock or Rock Veins
San-t'ai-kou	Euxenite	2	Magnetic iron ore Iron sulfides Spilositic eclogite Black mica	Gneissose granite, black mica-pegmatite
	Orthite	1	Black mica	Same as above
Ta-fang-shen	Euxenite	2	Same as above, excluding iron sulfides	Same as above
Nan-kou	Euxenite	1	Tourmaline	Gneissose granite, tourmaline-pegmatite

Figure 3 indicates in detail the zones of uranium-bearing pegmatite of the second body of ore shown in Figure 4. In the formation of euxenite, a propensity for forming in the midst of rocks rich in potassium such as plagioclase, and orthoclase (potash-feldspars) is apparent. This is a most significant fact.

The grouping of the minerals from the outside inward may be differentiated into three or five zones as follows:

I. Outer Zone	1. Graphic Intergrowth of Quartz-Perthite Zone
	2. Plagioclase-Perthite Zone
II. Inner Zone	3. Euxenite-bearing Quartz-Microcline-Plagioclase Zone
	4. Euxenite-bearing Quartz-Microcline-Perthite Zone
III. Center Zone	5. Microcline-Euxenite Zone

D. **Description of Ore Beds**

1. San-t'ai-kou Ore Bed

This bed is formed by three bodies of ore; Bodies No 1 and No 2 contain euxenite; Body No 3 contains orthite. Body No 1 is the main body of ore and is richest in quality.

a. Body No 1

It was here that the euxenite was first found. It occurs in various sizes, from the size of a bean, or one's finger, or one's fist to that of a cow's head, scattered through the mother rock. The yield of euxenite is 0.01-0.02 percent. The body is roughly lens-shaped and lies in a line slightly east of north; its inclination is nearly vertical. It is about 15 meters wide at the widest point, and about 50 meters long. Its zonal structure is quite marked. Major constituents are quartz-feldspar, orthoclase, microcline, perthite, and plagioclase. Minor constituents are small amounts of black mica.

b. Body No 2

This is about 50 meters north of Body No 1. Its major constituents are similar to those of Body No 1; but the minor constituents are black mica,

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magnetic-iron ore, iron pyrites in cubic crystals, the interior of which has almost become limonite, and green eclogite ($Ca_3Al_2Si_3O_{12}$), etc. The body is 35 meters long and 10 meters wide at the widest point. The euxenite occurs scattered through the rock in bean-or finger-size pieces. The proportion of ore to rock is less than in Body No 1, and the amount of ore produced is quite small.

c. Body No 3

This body of ore lies at the foot of a precipice, northwest of Body No 1. It is about 20 meters long, and 5 meters wide at its widest point. In it is to be found only orthite of prismatic-shaped crystals, 1.2 meters long, 0.5 meter in diameter, and weighing about 200 kilograms. The major constituents are quartz and feldspar, similar to Body No 1. The minor constituents are black mica, magnetic-iron ore, and orthite.

2. Nan-kou Ore Bed

This ore bed lies between those of San-t'ai-kou and Ta-fang-shen, on a hill about one kilometer south-southeast of the hamlet of Nan-kou, and is composed of two strips of pegmatite rock. They are over 25 meters long and 8-10 meters wide; their long axes lie northeast-southwest. Principal constituents are quartz and feldspar, perthite, orthoclase, microline, and plagioclase. Accompanying these are small amounts of dark green or black tourmaline. This is known as tourmaline pegmatite. Its zonal structure is indistinct; it is coarse-grained, and its quartz and feldspar disintegrate easily. Its euxenite content is small; occasional finger-size pieces are found in it, whose value is so small as to be hardly worth mining.

3. Ta-fang-shen Ore Bed

This ore bed consists of two lens-shaped bodies; the long axis of the first one lies east - west and is about 75 meters long; the second one, about 40 meters long, lies at the crest of a hill about 200 meters north of the first, with its long axis on a northeast-southwest line. Major constituents of both bodies are quartz and feldspar, orthoclase, microline perthite, and plagioclase. Minor constituents are magnetic-iron ore and considerable black mica. Its zonal structure is quite distinct. Euxenite in very irregular shapes, rarely as large as a cow's head but commonly in fist-size pieces or smaller, is found scattered throughout the rock mass and sometimes is enveloped in the black mica. This bed of ore is inferior to that at San-t'ai-kou. When it was first mined in January 1945, more was taken from it (400-450 kilograms per month) than from San-t'ai-kou, but the usual monthly output later was about 200 kilograms.

II. Minerals in the Ore

1. **Euxenite**

A specimen of uranium-ore deposit of pegmatite-type, in the collection of the Geological Investigation Bureau, Northeast Ta-lu Science Institute, is 0.37 meters long, 0.18 meters in diameter and weighs about 20 kilograms. Figure 5 indicates the lay of this specimen as found at San-t'ai-kou.

Its physical properties are as follows: Rhombic system; but rarely found as crystals, usually in massive form, without cleavage; conchoidal or uneven fracture; brittle and weak; hardness 6.5; specific gravity 4.60-4.99; resinous-greasy or metallic-vitreous luster; brown or black in color, with yellowish-brown or reddish-brown streaks; strongly radioactive. (Refer to tests for light effect on photographic plates.)

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a. Test No 1

Panchromatic plate used, Panchrom, was made by the Fuji Company. Duration of exposure was one week. Method: The four pieces of mineral were ground smooth on one face and placed on the plate in close contact with it. The positive picture made from the exposed negative plate shows ash-gray areas which indicate euxenite, and lighter spots which indicate some mineral more powerfully radioactive than euxenite, which may be betafite (?). The lines probably indicate irregular net-like cracks and fine veins of quartz and feldspar.

b. Test No 2

Plate used was the same as that used in Test No 1. Duration of exposure was one week. Method: The euxenite was pulverized and spread upon the plate. /Two electroplate reproductions of the photographs showing the results of the tests are given in the text. The results of Test No 1 are as described above. There is no description given of the results of Test No 2 beyond the very poor photograph shown. Both plates are too poor to allow reproduction in this report./

The outside surfaces of the euxenite bear evidence of weathering and disintegration, and have a tawny or brownish covering filament of some substance of secondary formation. Thin flakes when seen under the microscope exhibit an irregular network of well-defined cracks, 0.01 - 0.1 millimeters in width, and lining these cracks are fine veins of quartz, feldspar, and black mica. Translucent light appears a deep yellow in color; thick flakes, a brownish color. Reflected light is ashen in color. Refractive quality is very high, $N = 2.06 \sim 2.24 \pm$. Very thin flakes show very weak double refraction.

Results of analysis of 0.1 gram of concentrate in the Analytical Laboratory, Natural Science Department, Imperial University, Tokyo are as follows: (Specific gravity, $d^{18}_{40} = 4.88$)

$(Nb_1Ta)_2O$	33.83%	UO_2	3.81%	SnO_2	1.01%
TiO_2	22.31%	UO_3	1.41%	Na_2O	0.18%
$(Y.Er)_2O_3$	2[illegible]3%	FeO	3.41%	K_2O	0.04%
Ce_2O_3	0.32%	ThO_2	0.97%	CaO	0.08%
MgO	0.00%	Al_2O_3	2.80%	H_2O (+)	4.08%
MnO	0.60%	SiO_2	1.31%	H_2O (−)	0.81%

The chemical composition of this mineral is very complex, and there are many opinions as to its chemical structure. However, Nakai Toshio gives the following formulas based on the results of the foregoing analysis:

$R^{III}(NbO_3)_3 \cdot R_2^{III}(TiO_3)_3 \cdot R^{II}TiO_3 \cdot 3H_2O$. This formula is made up of the simplest formula for euxenite which is

$R^{III}(NbO_3)_3 \cdot R_2^{III}(TiO_3)_3 \cdot \frac{3}{2}H_2O$ (See "The Euxenite of Hai-ch'eng Hsien,":by Nakai Toshio, No 35 of a series, Chemical Research in Rare-Element Ores Produced in East Asia, Japan Magazine Society, 1939, pp 377-381) with the addition of $R^{II}TiO_3 \cdot \frac{3}{2}H_2O$.

This specimen of mineral weighing one gram contained the following quantity of radium (as per results of analysis by Nakai):

1.49×10^{-8} Ra/g, which is equivalent to 1.49×10^{-5} percent. According to the above analysis, the mineral contained 3.81 percent of UO_2 and 1.41 percent of UO_3; that is, in one gram of mineral there was 0.0453 grams of uranium. From this, the ratio of radium to uranium was

$$\frac{Ra}{U} = \frac{0.149 \times 10^{-7}}{0.0453} = 3.29 \times 10^{-7}.$$

Thus, we may judge what the facts are as to the balance between radium and uranium.

Next, as a corollary to the foregoing, an analysis was made of the yellowish-brown disintegrated rock material which surrounded the mineral, and the results were:

The radium content of one gram of the sample was $7.62 \times 10^{-11}_{\ g}$ Ra/g, which is equivalent to 7.62×10^{-9} percent.

The uranium content was 0.30 percent of U_3O_8, which is equivalent to 0.0025 gram of uranium. The ratio of radium to uranium was thus:

$$\frac{Ra}{U} = \frac{0.000762 \times 10^{-7}}{0.0025} = 0.31 \times 10^{-7};$$ that is, the proportion of radium to uranium in the enveloping rock was extremely small.

2. Orthite

The chief occurrence of this mineral was in Body No 3 of the San-t'ai-kou ore deposit, mainly in large prismatic-shaped crystals. A specimen which Liu uncovered was 0.5 meter long, 0.2 meter wide, 0.1 meter thick, and weighed about 24 kilograms. In January 1945, a large crystal was found that was 1.2 meters long, 0.5-0.6 meter in diameter, and weighed over 200 kilograms. This crystal is still at the San-t'ai-kou mine. Orthite, like euxenite, is found scattered amidst the biotite-pegmatite. The crystals are marked by a network of well-developed cracks, and these are filled with the intrusion of fine veins of feldspar and quartz. The surface has a weathered and disintegrated appearance, and is covered with a thin layer of earthy material.

Physical properties of orthite are as follows: Monoclinic crystal system; submetallic, resinous or vitreous luster; cleavage disposition very small; brittle and weak; conchoidal or uneven fractures; brownish-black color with ashy or greenish streaks; hardness 5.5-6.0; specific gravity 3.5-4.2; fragments are translucent; very slightly radioactive.

Chemical composition, according to Dana, may be expressed as $H_2O.4RO.5R_2O_3.6SiO_2$.

(But R^{II} = Ca, Fe, etc; R^{III} = Al, Fe, Co, Di, La, and Y).

Ce: 20 percent $\pm$; Y: 1 - 2 percent; Th_2O_3: trace - 3 percent. According to the analysis by Nakai, the radium content of the mineral was

$1.34 \times 10^{-10}_{\ g}$ Ra/g.

F. Uranium-Bearing Orec of the World

[Since this information is well known, no translation has been made.]

G. Principal Uranium-Producing Areas of the World

[Since this information is well known, it has not been translated, with the exception of the following:]

Czechoslovakia: Jachymov ore bed

Mineral -- pitchblende, accompanied by silver and cobalt.

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Production -- radium, about 5 grams per year, 1936-39; uranium, U_3O_8, 34.80 pounds in 1935; U_3O_8, 35.40 pounds in 1936; U_3O_8, 24.30 pounds in 1937.

Russian Turkestan (Caucasus):

Mineral -- Tyuyamunite.

[Appended figures follow.]

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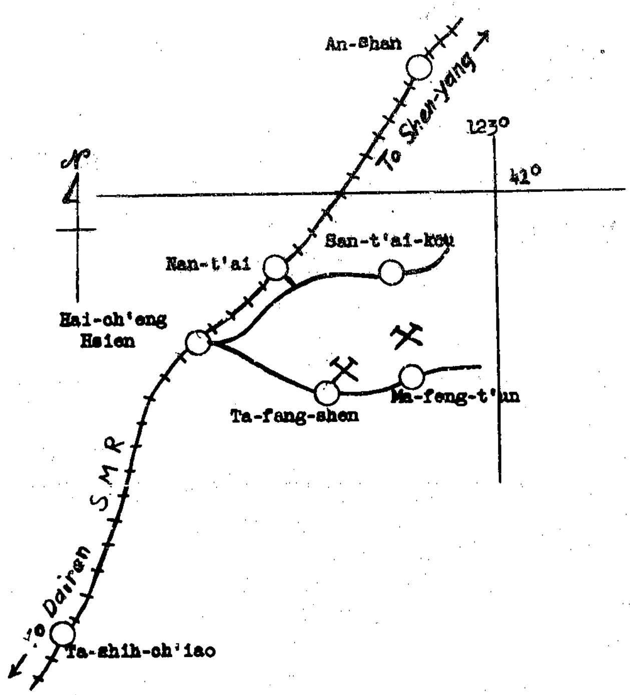
Figure 1. LOCATION OF ORE BEDS
Scale - 1:500,000



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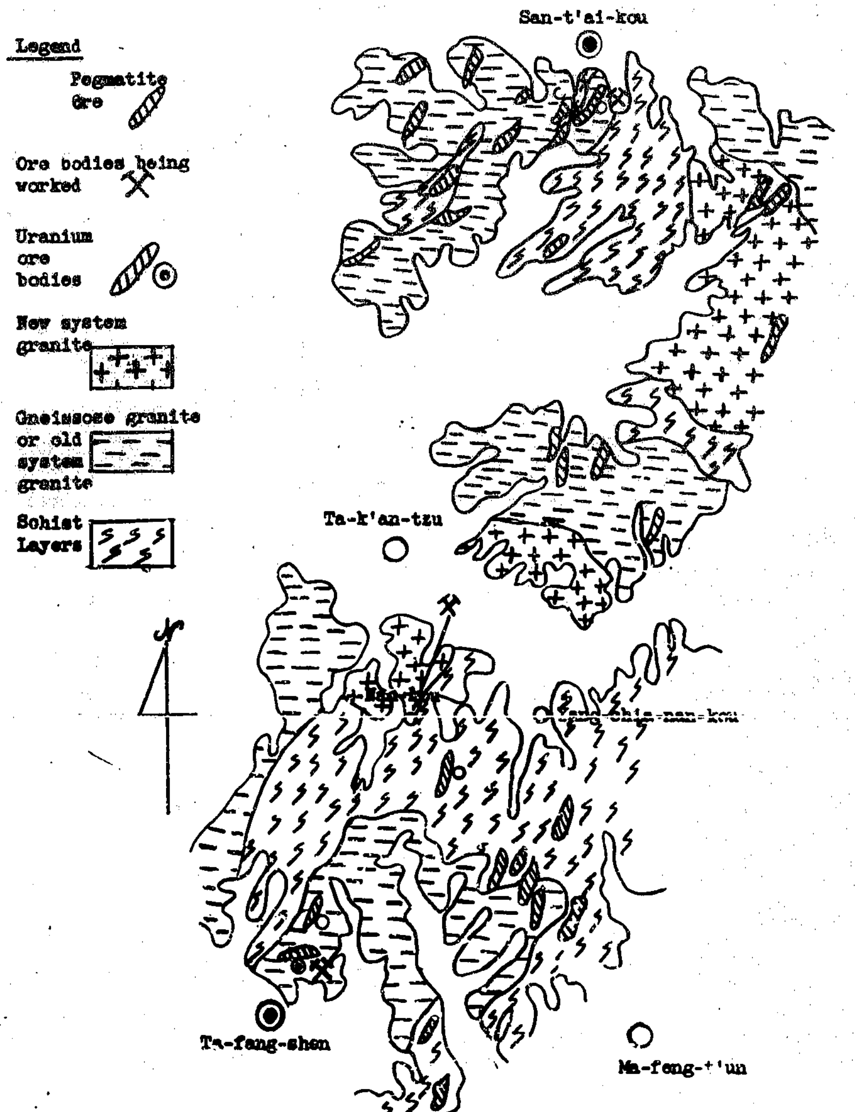

Figure 2. The Geological Nature and Distribution of Ore in the San-t'ai-kou--Ta-fang-shen Area in Hai-ch'eng Hsien, Liaoning Province

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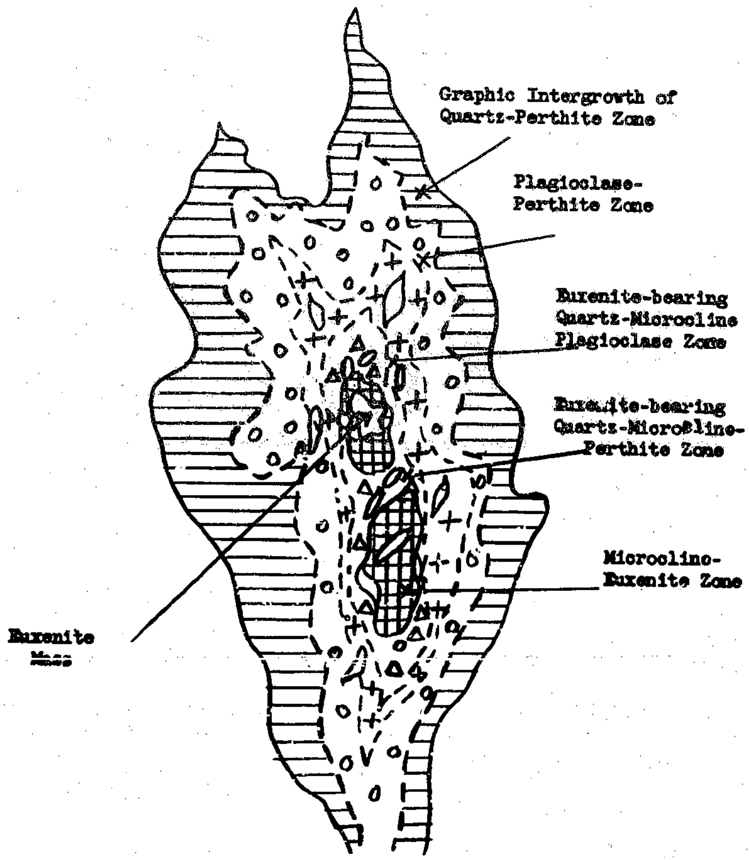

Figure 3. SAN-T'AI-KOU ORE BED

Ore Body No 2 of Figure 4
Showing Zones of Uranium-bearing Pegmatite

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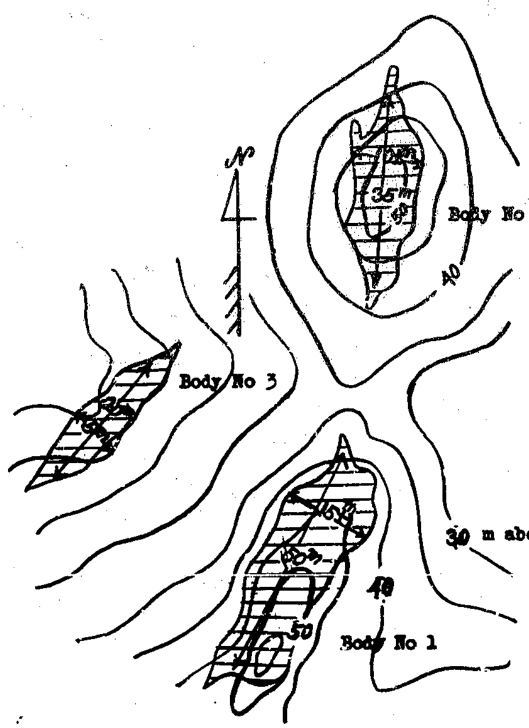

Figure 4. SAN-T'AI-KOU ORE BED

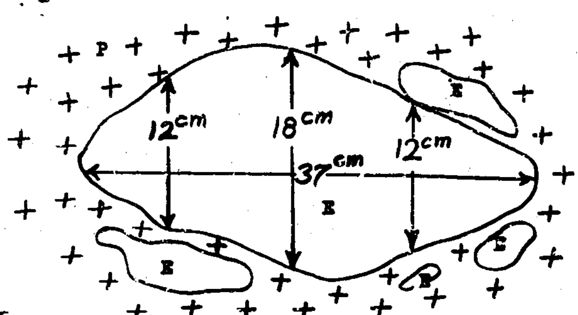

Figure 5.

E . . . . . Euxenite
P . . . . . Pegmatite

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